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IMPACT DYNAMICS RESEARCH ON COMPOSITE TRANSPORT STRUCTURES

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SUMMARY

A NASA Langley Research Center crash dynamics research program has been formulated to investigate the response characteristics of generic composite components subjected to simulated crash loadings. The new program has been arranged to focus on three levels: the laminate level for material properties such as energy absorption and the behavior of skin materials; the element level focusing on more complex geometry and behavior of beams, frames (rings); panels and arches; and the substructure level dealing with cylindrical shells, floors, and larger scale components. Supporting analytical efforts are also a part of the research program. This paper summarizes some of the experimental and analytical work being undertaken under the composites program with the goal of gaining an understanding of the behavior of generic composite structural components under crash related loading conditions.

N05-21017#

INTRODUCTION

Composite materials have in the past few years gained increased use in the aircraft industry because of their excellent mechanical properties, tailorability, and light weight. Much research has been concentrated on composite structures to determine their strength capabilities and to characterize failure mechanisms, damage tolerance, and fatigue behavior under in-flight conditions. Any potential problems with failure, damage, or fatigue (see reference 1) must be resolved before sufficient confidence is established to fully commit to composite materials. Additionally, under realistic and survivable crash conditions, the design of a composite fuselage must assure that occupants have every reasonable chance of escaping serious injury. In areas where failure could create a hazard to occupants, the impact dynamics capabilities (crashworthiness) and global response of composite structures need to be well understood. To achieve this understanding for a composite fuselage shell design, an extensive data base supported by appropriate analyses will be required. Investigations of structural response and integrity of composite fuselage structural components subjected to typical crash loading conditions are therefore required.

This paper reviews some of the experimental and analytical efforts being undertaken to investigate the response of composite and aluminum structures with the goal of gaining an understanding of the behavior of generic composite structural components under simulated crash loading conditions.

IMPACT DYNAMICS RESEARCH

NASA Langley Research Center has been involved in crash dynamics research (crashworthiness) of general aviation aircraft for over 10 years (see figure 1). In this program 32 crash tests were performed under controlled free-flight impact conditions to determine the dynamic response of airplane structures, seats, and occupants during a crash (refs. 2 to 4) and to determine the effects of flight parameters at impact on the load and structural damage experienced by the airplane and occupants (refs. 5 and 6).

Recently, research emphasis has shifted to impact dynamics of transport-category aircraft. The FAA and NASA have obtained a Boeing 720 airplane to be used in a remotely piloted air-to-ground controlled-impact demonstration (CID) test. Data from this fully instrumented airplane demonstration test will contribute to a metal airplane benchmark data base for comparison with future tests of composite structures.

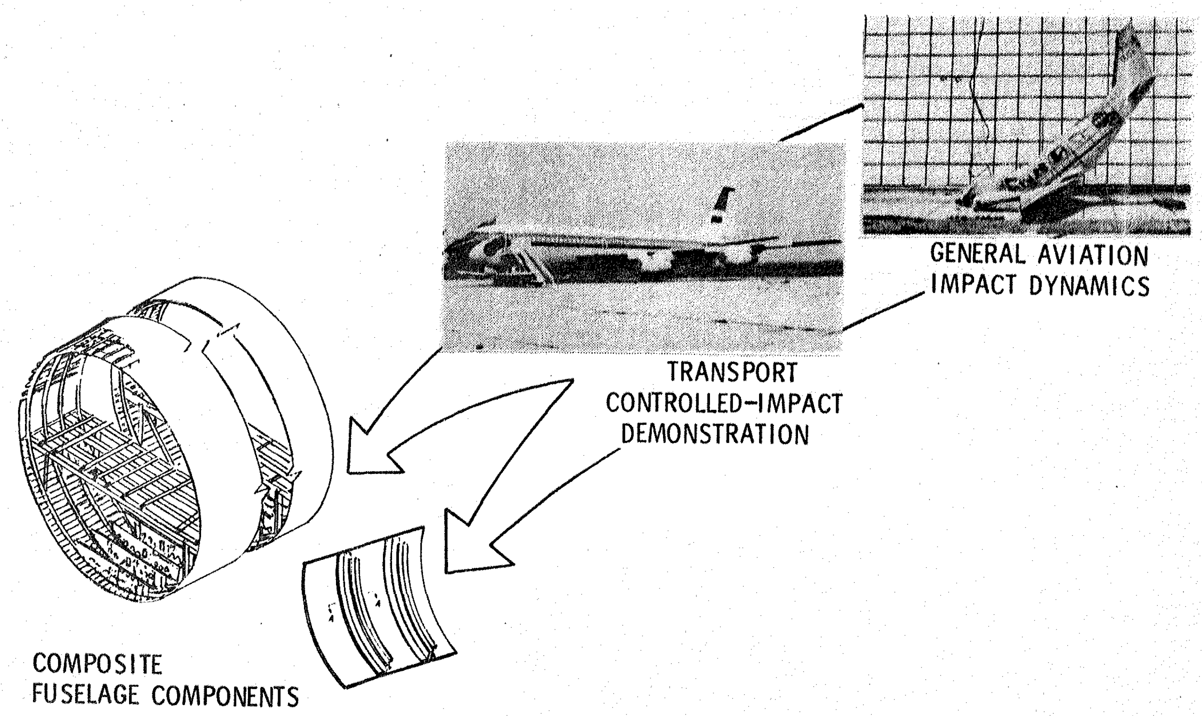


Figure 1

TYPICAL TRANSPORT FUSELAGE STRUCTURE

It is apparent from figure 2 that a typical transport fuselage, whether metal or composite, is composed of many different elements. For example, in figure 2, structures such as curved and flat panels, curved and straight beams (frames, stringers, and floor beams) as well as cylindrical sections (on a larger scale) are apparent as elements and substructures of the aircraft. In a crash situation these structures may experience loading conditions which could cause failure and thereby create hazards to occupants of the aircraft. Thus any investigation concerned with impact dynamics should address the global response and integrity of generic composite fuselage structural components subjected to typical expected crash loading conditions to provide an understanding of their behavior under such loadings.

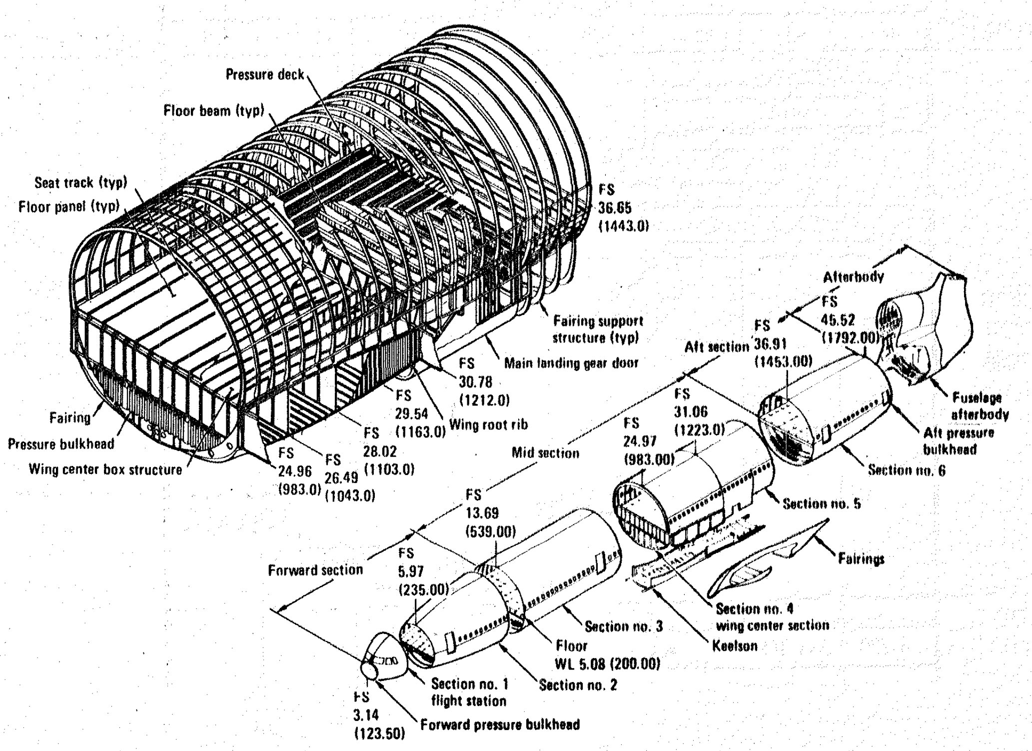


Figure 2

RESPONSE CHARACTERISTICS OF GENERIC COMPOSITE COMPONENTS TO SIMULATED CRASH LOADINGS

A research program has been formulated to investigate the response characteristics of generic composite components to simulated crash loadings. As shown in figure 3, this new program has been arranged to focus on three levels: the laminate level for material properties such as energy-absorbing qualities and the behavior of skin materials; the element level focusing on more complex geometry and behavior of beams, frames (rings), arches, and panels; and the substructure level dealing with cylindrical shells, floors, and large-scale components. The metal baseline is represented by the Boeing 720 controlled-impact demonstration test as well as some metal comparison in the laminate, element, and substructure levels themselves.

The goal of research on the generic components is to provide a data base and understanding of generic composite component behavior subjected to crash loading conditions supported by validated analytical methods. To help achieve this goal, in-house research, contractural efforts, and university grants are included in the program.

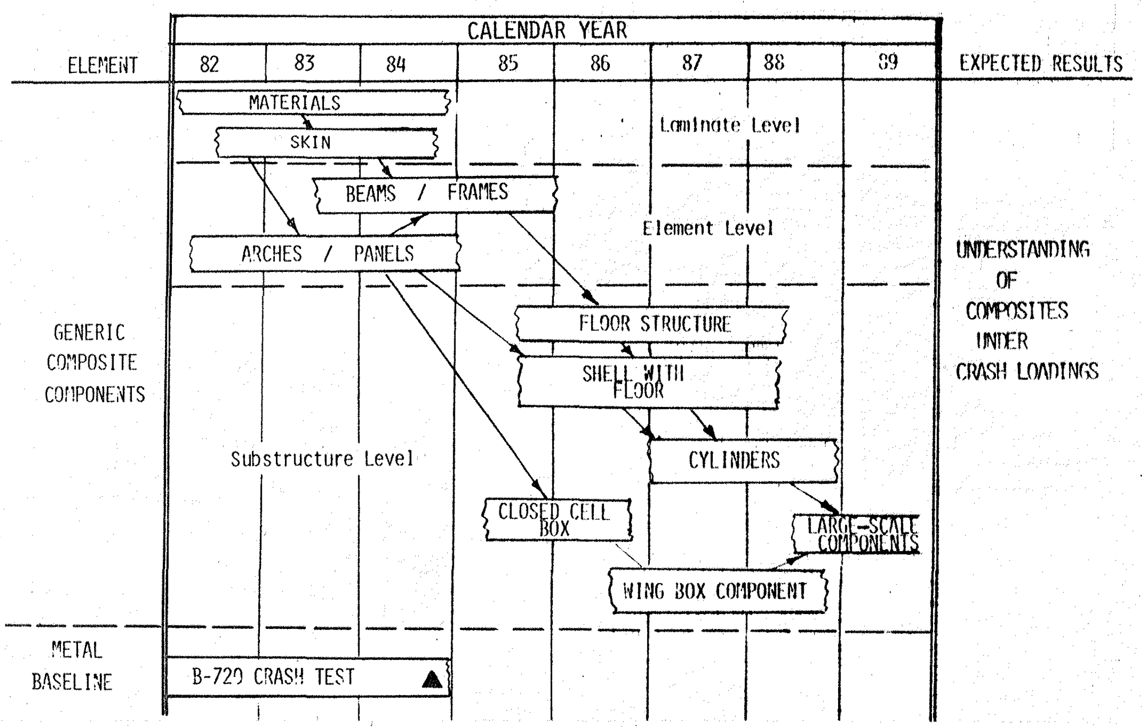


Figure 3

COMPOSITE LAMINATE LEVEL STUDIES

On the laminate level of the program, the thrust of the investigations of composite materials (see figure 4) involves:

- study of energy absorption characteristics of laminate materials
- characterization of behavior of metal and composite laminates under abrasion (sliding) forces associated with gears up, belly landings, or collapsed-gear situations
- assessment of response of laminates (skins), both all graphite/epoxy and hybrid designs, to representative crash loads which simulate inplane and out-of-plane tearing forces which can be experienced during a crash event

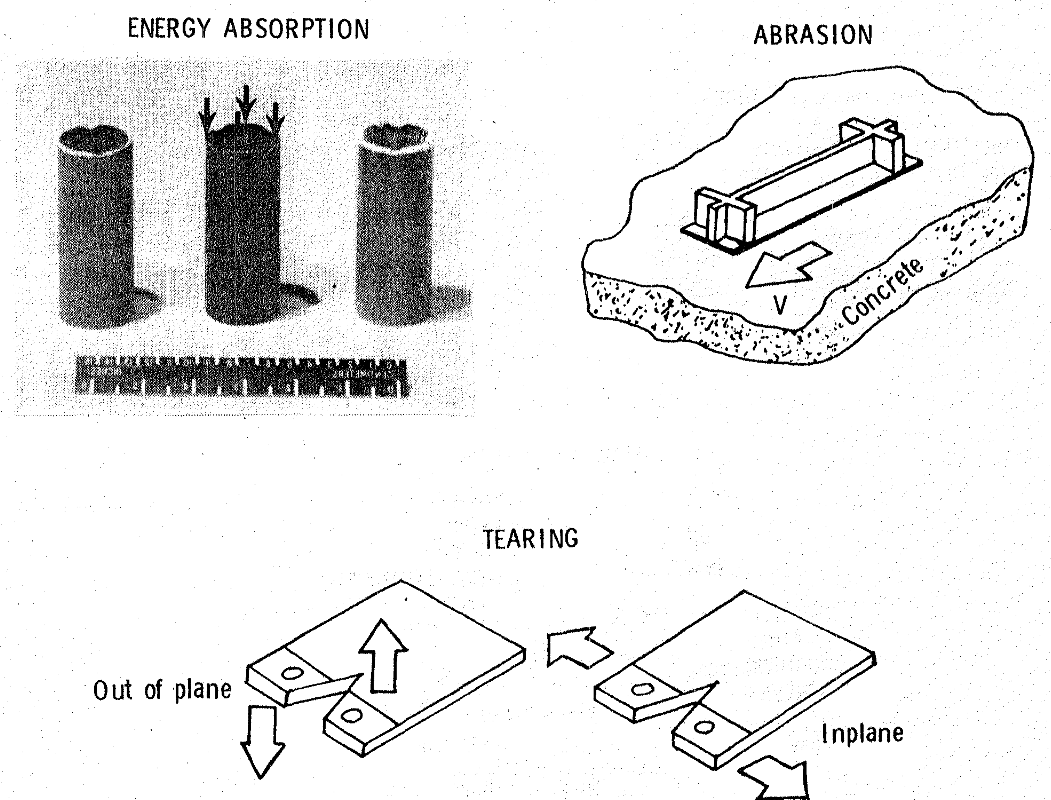


Figure 4

ENERGY ABSORPTION OF COMPOSITE MATERIALS

A joint US Army/NASA program is underway to study energy absorption characteristics of selected composite material systems (ref. 7). As depicted in figure 5, composite compression tube specimens (chosen for stability and ease of manufacturing) were fabricated with both tape and woven fabric prepreg using graphite/epoxy (Gr/Ep), Kevlar[1] epoxy (K/Ep), and glass/epoxy (Gl/Ep). Typical test results of static and dynamic specific sustained crushing stress (σ/ρ) versus ply orientation are presented. For the Gr/Ep the results varied significantly with ply orientation. In general the Gr/Ep tubes absorbed more energy than the Gl/Ep or K/Ep tubes for the same ply orientation. The [0/$\pm$ 15] Gr/Ep tubes absorbed more energy than the aluminum tubes. Failure mechanisms for the Gr/Ep involve interlaminar cracks at the crushing front which produce beam-like elements that carry load until they buckle and subsequently fracture. The interlaminar cracks propagate and the crushing continues. K/Ep exhibits a ductile folding mode of energy absorption where extensive interlaminar cracks occur, but fiber fracture is not prevalent. Based upon the knowledge of the different failure mechanisms, follow-on efforts are underway to exploit the failure patterns to advantage in impact situations. High-strain-to-failure graphite hybridized with Kevlar is being tested, and initial results are promising in that energy absorption higher than aluminum is achieved together with desirable post-crush integrity. Material data such as discussed will be useful in designing efficient energy-absorbing structures that have good post-failure structural integrity.

[1]Kevlar is a registered trademark of Du Pont.

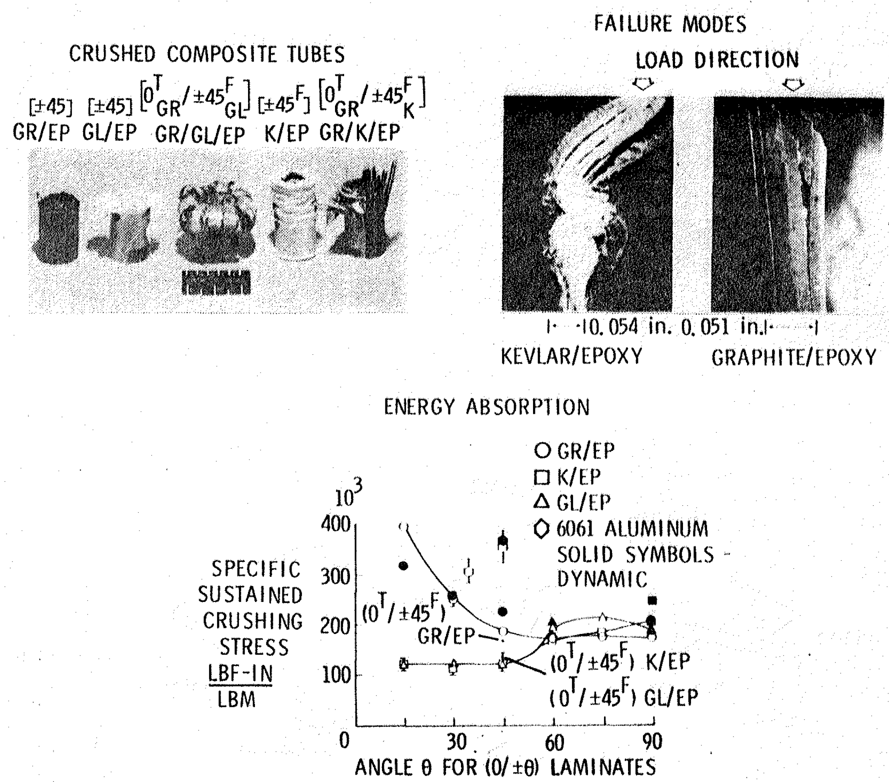


Figure 5

TEARING OF FUSELAGE SKIN PANELS
Inplane Loads

A potential crash loading condition that airplane skin panels could experience includes tearing forces during slide-out. A series of 24 tearing tests were therefore performed (on contract NAS1-15949 to Lockheed-California) on aluminum, graphite/epoxy, and two hybrid graphite/epoxy/glass laminates to experimentally assess the response of composite laminates to simulated tearing forces that might be experienced by lower fuselage skin panels during a crash event. The typical specimen configuration, inplane energy absorption, and load deflections are shown in figure 6. Load deflection data for the 5 different specimens under inplane (mode 1) tearing loads indicate that the hybrid 1 sustained the highest load and exhibited a more plastic regime from yield to ultimate and post-failure. The Gr/Ep and hybrid 2 sustained essentially the same peak load; however, the Gr/Ep shows an almost total loss of load-carrying capability after peak load, whereas the hybrid 2 had a plastic behavior similar to the hybrid 1 but at lower loads. The aluminum specimens show gradual loss of load-carrying capability after failure with the 2024-T3 aluminum exhibiting a peak load approximately the same as the Gr/Ep and hybrid 2.

The energy absorption (area under load deflection) for the inplane tearing loads indicates that 2024-T3 and the hybrid 1 specimen had the highest absorption. The 7075-T76 aluminum and hybrid 2 specimens exhibited comparable energy absorption, but were somewhat lower than 2024-T3 and hybrid 1. The Gr/Ep specimen showed substantially the lowest energy absorption capability. When efficiency (specific energy) is considered, the trends are unaltered except the hybrid 2 material clearly performed better than the 7075-T76 material, and Gr/Ep on a relative basis was below 7075-T76.

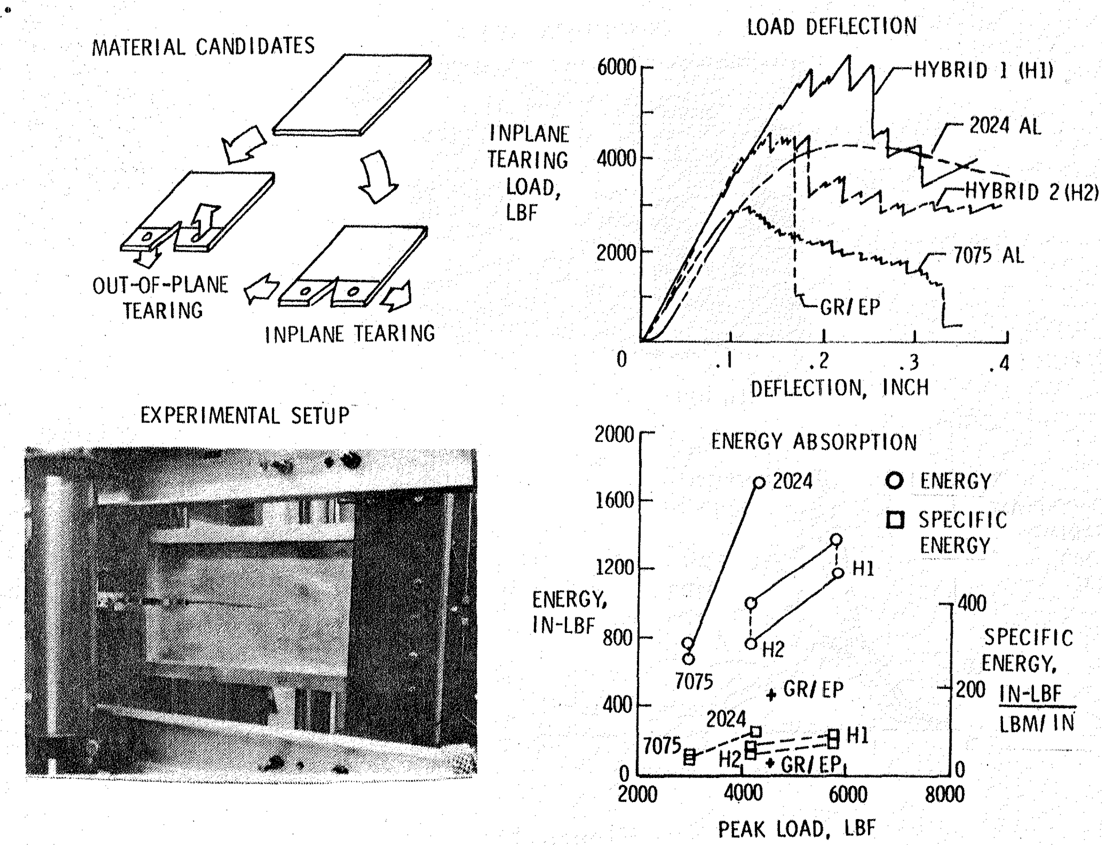


Figure 6

TEARING OF FUSELAGE SKIN PANELS
Out-of-Plane Loads

Tearing tests were also performed for out-of-plane forces (mode III) on the various metal and composite skin panels. A typical failed specimen, load deflections, and energy absorption are shown in figure 7. As may be noted, the peak loads sustained by each material specimen varied from 766 lbf for the 7075-T76 aluminum to 1800 lbf for the hybrid 1 panel. The deflections at peak load however are reasonably close, 1.6 to 1.8 inches for most all materials. The exception was the deflection of the Gr/Ep at 1.4 inches. The load deflection data indicate that both the Gr/Ep and the hybrid 1 specimens had a drastic loss of load-carrying capability following initial failure compared to the metal behavior. The hybrid 2 exhibits a more plastic-like deformation after initial failure and prior to peak load thus achieving higher energy absorption. Indeed, the results show that hybrid 2, hybrid 1, and 2024-T3 materials exhibit more energy absorption capability than the Gr/Ep or the 7075-T76 specimens. However, the specific energy (a measure of the design efficiency) shows Gr/Ep to be better than the 2024-T3. The trend indicates increased energy absorption for metallic materials going from 7075-T76 to more ductile 2024-T3 and for the composites going from Gr/Ep to hybrid 1 to hybrid 2. Since there was judged to be significant fixture interference for the hybrid 1 tests, it is not possible to predict exactly where this material should fit. From the test results and known material properties, it appears that ductility and relatively low shear stiffness are desirable characteristics to enhance crash performance of the composite materials subjected to both inplane and normal tearing forces during slide-out.

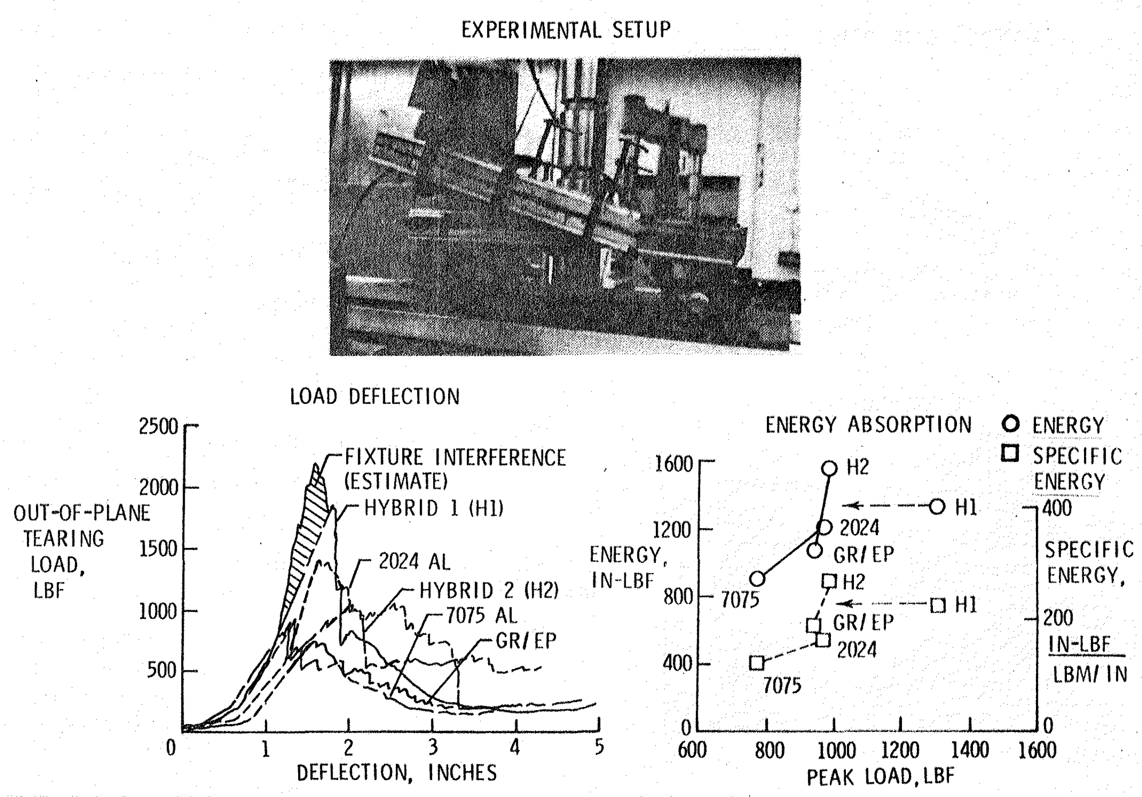


Figure 7

FRICTION AND ABRASION BEHAVIOR OF COMPOSITE SKINS

One consideration which can be important in the design of crashworthy airplanes is the abrasion and wear behavior of the skin material. In the last 5 years, at least a dozen transport airplanes have experienced collapse of the landing gear leading to sliding landings on runway surfaces (ref. 8). Typically, these transport airplanes slide 4000 to 5000 ft with touchdown velocities of approximately 140 mph. In some sections of the airplane, wear damage to the aluminum skin is considerable, although usually repairable. The anticipated use of composite materials in transport airplane/skins raises the question of how composite skins would behave under these circumstances as compared with current aluminum construction. Experiments were performed (ref. 9) to compare the friction and wear behavior of aluminum and composite materials when subjected to sliding or abrasion loading conditions. Four types of materials (aluminum, standard graphite/epoxy, aramid/epoxy, and toughened-resin composites) were used to fabricate small skin test specimens. The specimens were abraded (see figure 8) under conditions of varying pressures, abrasive surface textures, and surface velocities.

Comparisons of the materials were made based on coefficient-of-friction data and the wear rate (defined as the loss of thickness per unit of run time) as a function of the test variables. The composite materials exhibited wear rates 5 to 8 times higher than the aluminum, with the toughened-resin composites having the highest wear rates under identical test conditions. The wear behavior was a linear function of pressure, surface texture, and velocity. The coefficient of friction of each material was independent of the test variables. The standard graphite/epoxy composite had a coefficient of friction (0.10 to 0.12) approximately half that of aluminum (0.20), whereas the aramid/epoxy and toughened-resin composites had coefficients of friction about the same as aluminum. The increased wear rate of the composites will influence the question of repairability and strength degradation of understructure on the aircraft.

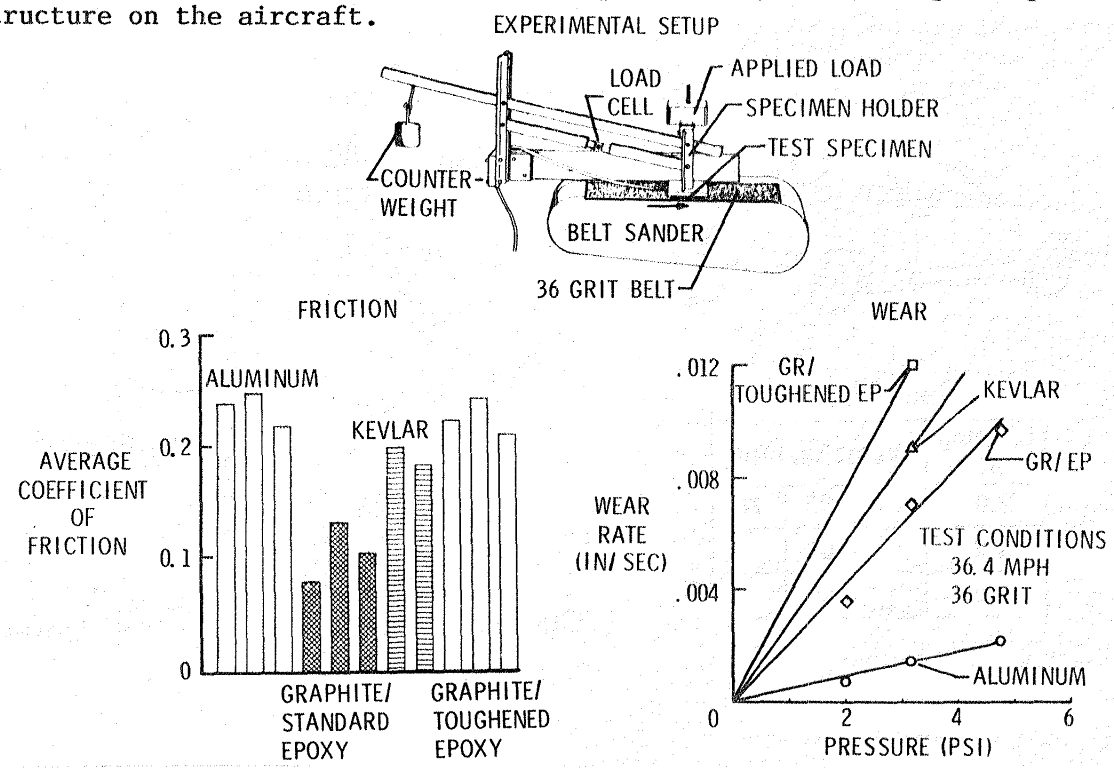
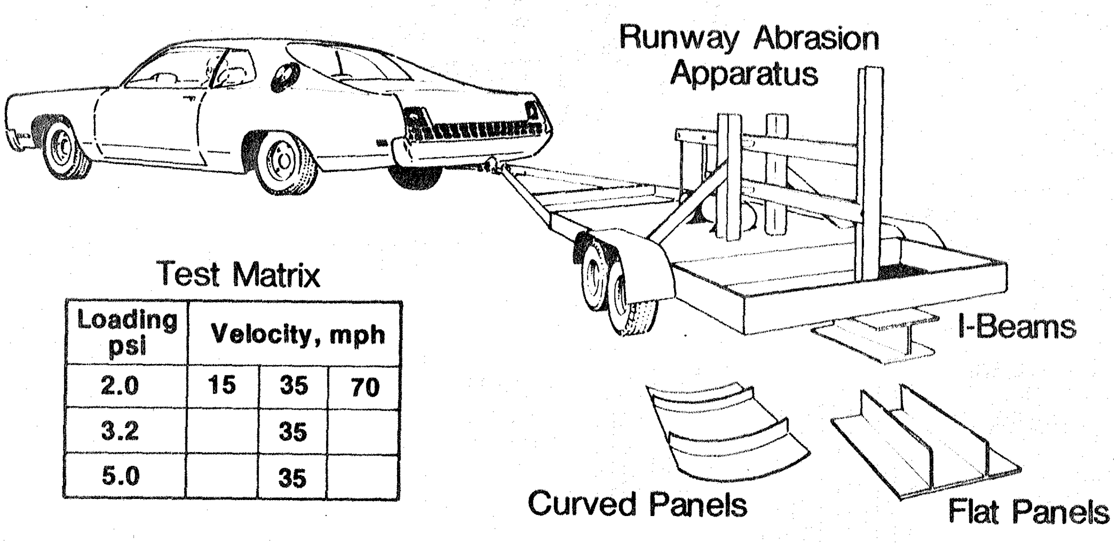


Figure 8

RUNWAY ABRASION STUDY

To extend the data base from laboratory studies on friction and wear behavior of composite and metal skin materials, abrasion tests will be conducted on actual runway surfaces. These results will provide data for a comparison with laboratory results. As shown in figure 9, a runway abrasion test apparatus will be used to obtain friction and wear characteristics of metal and composite I-beam/skin specimens, and curved and flat panels. The test matrix, which encompasses the pressure and velocity range used in the laboratory abrasion studies, will provide wear and friction data versus pressure for a constant velocity, wear and friction versus velocity for constant pressure, and other pertinent measurements on the behavior of the specimens on actual runway roughnesses in the same texture range as the laboratory experiments. It is hoped that correlations will permit the use of the laboratory tests for determining wear and friction behavior of skin panels.



Test Matrix

Loading psi	Velocity, mph		
2.0	15	35	70
3.2		35	
5.0		35	

Figure 9

COMPOSITE ELEMENT LEVEL STUDIES

As the research effort moves from the laminates to the elements of the composite dynamics program of figure 3, the geometry of the composite components becomes somewhat more complex. For example, figure 10 illustrates several typical structural components being used in the element level studies. Tests and related analyses or analytical simulation studies are being undertaken on: shallow circular cylindrical panels subjected to lateral loads (line load); the impact of similar shallow panels on a contact plane, I-beams typical of keelsons found in the lower crown of a transport fuselage subjected to crushing loads; and the dynamics of composite frames (rings) under impact conditions. The study of the impact dynamics of such structural elements represents what are considered to be prudent first studies of the response of subassemblies or individual components of the fuselage under dynamic crash-related loadings prior to the study of the response of a complete fuselage under such loadings.

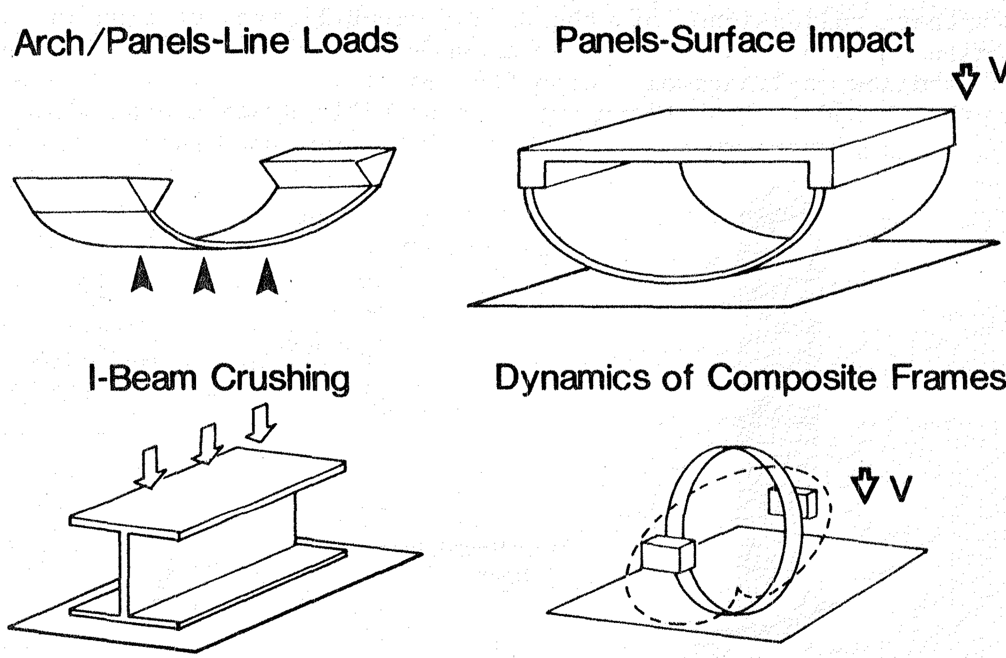


Figure 10

RESPONSE OF SHALLOW CYLINDRICAL COMPOSITE PANELS

An important aspect of crash dynamics is the study of large displacement response of structural components under impact loads. For example, in a gears-up landing of an aircraft not only are the structural components on the underside of the fuselage subjected to the abrasive and tearing loads previously discussed but they are also subjected to lateral impact loads. Initial studies on circular composite panels have been undertaken that include both closed-form analytical solutions extended to handle orthotrophic materials (see refs 10 and 11) and finite-element analysis (DYCAST, ref. 12) as well as experimental investigations. Large displacement response (both static and dynamic) of composite panels (with radii, thicknesses, and arc lengths), which are representative of fuselage panels on transport aircraft, has been determined. Figure 11 presents a photograph of the displacement-controlled loading apparatus (refs. 10 and 11) along with representative theoretical and experimental results on a $[(90/0)_3]_s$ lay-up composite panel (radius, R = 55.42 in.). Although the simple support boundaries do not match those that exist for transport fuselage panels, the behavior of panels in this study does provide information for long panels (width >> than thickness). Closed-form analytical predictions are solid lines with symbols representing experimental data. Non-dimensional load displacements and load thrust are presented, and correlation between theory and experiment is quite good. Results from this study demonstrated that panel shallowness, material orthotrophy, and stacking sequence influence the non-linear static response of graphite/epoxy curved panels. The response of the panels may exhibit no instability, snap-through instability at a limit point, or snap-through at a bifurcation point, depending upon the values of circumferential extensional stiffness, bending stiffness, radius, and semi-opening angle of the panel. DYCAST analysis results are to be determined for comparison with the closed-form solutions. It is anticipated that good correlations will be found, thus providing further validations of the DYCAST capabilities but also indicating the greater efficiency and ease of use of the closed-form solutions to understanding the behavior of shallow cylindrical composite panels. Furthermore, the work may be extended to other boundary conditions and to a possible dynamic analysis.

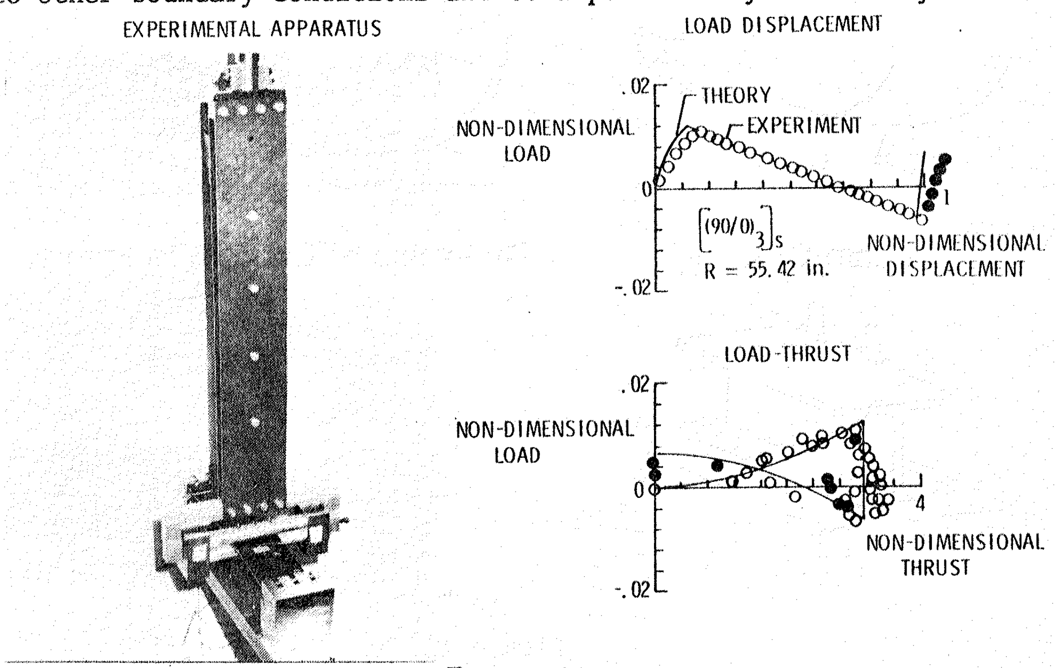


Figure 11

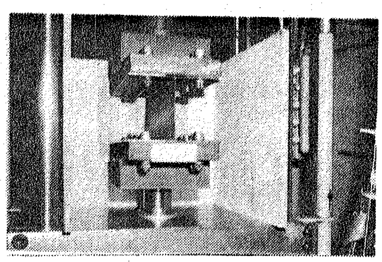
CRUSHING BEHAVIOR OF COMPOSITE KEELSON-LIKE BEAMS

Static loading tests simulating the normal crushing force associated with a crash landing were performed on I-beam configurations selected as representative of fuselage structural components, such as a single-member frame or keelson design. These tests were also performed by Lockheed-California Company on contract NAS1-15949 for NASA LaRC to investigate the effects that variations in materials and ply lay-up have on the structural response and failure modes of these components. Five configurations, one aluminum, two graphite/epoxy, and two hybrid I-beams, were designed to have the same bending stiffness, web column strength, and at least the same web shear stiffness.

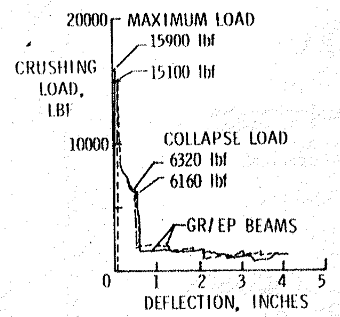
A typical setup for the crush testing and the failed I-beam crush elements are shown in figure 12. The load deflection data indicate that all the specimens exhibited a sharp buildup of load at a deflection (crush) of less than 0.2 inches. A major loss of load-carrying capability in the graphite/epoxy specimens as a result of buckling/delamination occurred after crushing less than 0.8 inches. The 7178 aluminum specimen ruptured, thus losing all load-carrying capability. The Gr/Ep specimens retained some residual load capability out to about 4 inches of crush; however, the sustained load was only about 10% of the peak failure load. Specific Peak Force (SPF) and Specific Energy Absorption (SEA) values were determined by dividing the peak force and energy absorption by the section weight-per-unit length for comparing the efficiency of the designs. From the results summarized in the table of figure 12, it can be seen that the hybridization of the graphite/epoxy I-beams with Owens-Corning S-2 glass strips (hybrid 2) influenced peak load but had negligible influence on total specific energy absorbed.

The crushing-test results indicate that designs of keelson-type I-beams using advanced composite materials have the potential of achieving both higher SPF and SEA values than 7178 aluminum. Areas of further evaluation should focus on boundary conditions, combined loads, and the effects of Kevlar; toughened resin systems, and high-strain graphite fibers, being developed under the Army/NASA energy absorption studies (figure 5), should be examined.

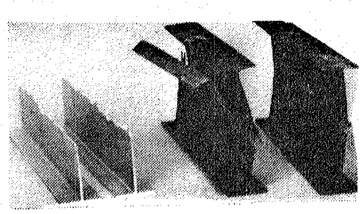
EXPERIMENTAL SETUP



TYPICAL LOAD-DEFLECTION



TYPICAL FAILED SPECIMENS



SUMMARY OF CRUSH TEST RESULTS

SPECIMEN MATERIAL	PEAK LOAD LBF	ENERGY ABSORBED TOTAL IN-LBF	ENERGY ABSORBED SPF LBF/(LBM/IN)	ENERGY ABSORBED SEA IN-LBF/(LBM/IN)
7178 AL	20000	6217	14620	45445
GR/EP	13000	4987	16414	62967
HYBRID 1	12000	7193	11952	71643
HYBRID 2	13000	5451	16414	68825
MODIFIED GR/EP	15500	8900	16298	93585

Figure 12

DYNAMIC RESPONSE OF COMPOSITE BEAMS

As previously indicated, the goal of the relatively new NASA composite impact dynamics program is to obtain an understanding of the structural response and integrity of generic advanced composite structural components appropriate to transport fuselage construction subjected to crash-related loadings. One effort on the element level of this program is an experimental and analytical study initiated under the NASA/Virginia Polytechnic Institute and State University Composites Program to determine the large deformation response and failure of composite structural beam elements subjected to transient dynamic loadings. The objectives of this study are: (1) to predict global failure; (2) to determine the strain rate effects, and (3) to quantify non-catastrophic damage of composite beams. Relative to the global failure, an analytical model will be developed to predict large deformation response and failure (with an appropriate failure criteria) for comparison with experimental results. Composite beams fabricated from different materials systems, with various stacking arrangements and geometry, will be dynamically tested in the apparatus shown in figure 13. The dynamic load will be applied to the end of the composite beam specimens in an eccentric manner to cause buckling of the beam due to bending. Load history, displacements, and strains will be determined under various impact conditions. Additionally, energy damage correlations will be investigated. It is anticipated that parameters which control the response and failure of the composite elements under impact loads will be determined during the study.

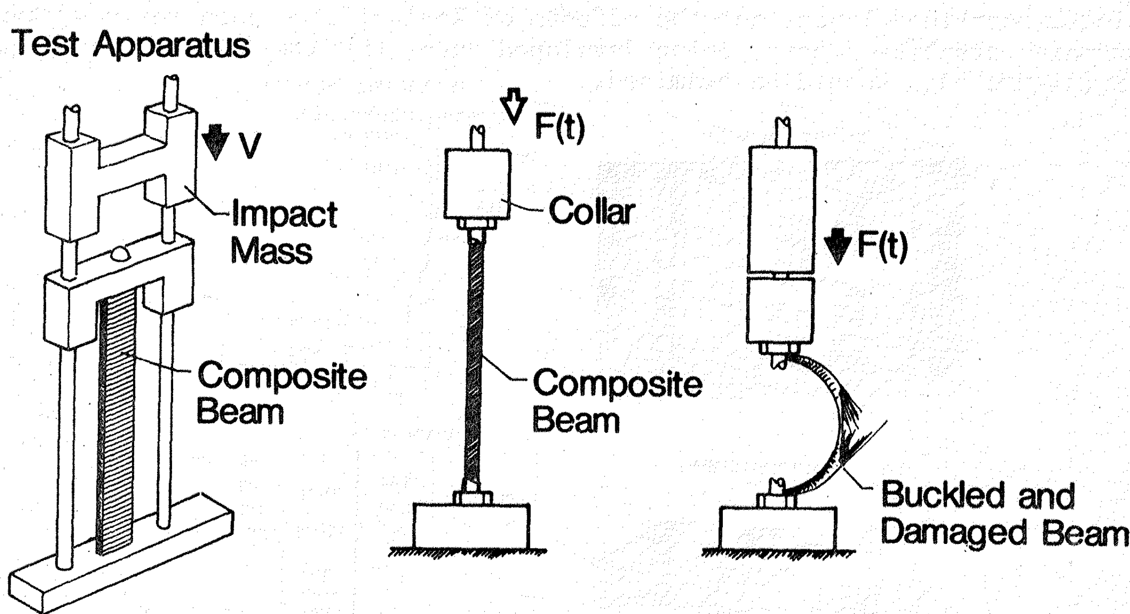


Figure 13

DYNAMICS OF CURVED COMPOSITE FRAMES

As shown in the typical airframe structure in figure 2, one very common structural element is the curved beams or frames of the fuselage. Consequently, another element being studied under dynamic loadings is the curved composite frame. The study will be concerned with the dynamic response and failure modes and loads which occur under impact. Curved composite frame specimens with an inner radius of 36 inches and a Z cross section typical of many such elements in transport fuselage construction are being fabricated for experimental evaluation. During the tests, bending-moment distribution, inplane tensile loads, and failure loads/modes will be determined for verification of and correlation with analytical data. In addition to the studies on the complete frames, various segments (quarter or half segments) will be available from damaged frames or untested specimens for experimental loading and study. As part of the study, a DYCAST model has been formulated and preliminary analytical static and dynamic predictions for a curved composite Z-section frame are presented in figure 14. DYCAST-predicted static-moment (M) distribution and circumferential zero-moment locations are compared to results for a uniform ring loaded by its own weight (from ref. 13). Excellent comparison is noted for both the distribution of moment and null points computed by DYCAST. Additionally, the DYCAST model was used to predict dynamic responses wherein mass was added to the outer horizontal radius. The altered (from static results) moments are shown along with predicted failure locations of the frame during the impact loading. It is anticipated that predicted global failure locations and loads such as these will be verified experimentally, and detailed analysis of critical areas can be conducted using laminate analysis with loading conditions to evaluate whether failure is actually predicted. Verified analytical frame models should be useful in constructing analytical models of complete composite fuselage structures and provide accurate stiffness data and expected failure locations and behavior of more complex fuselage structure under impact loads.

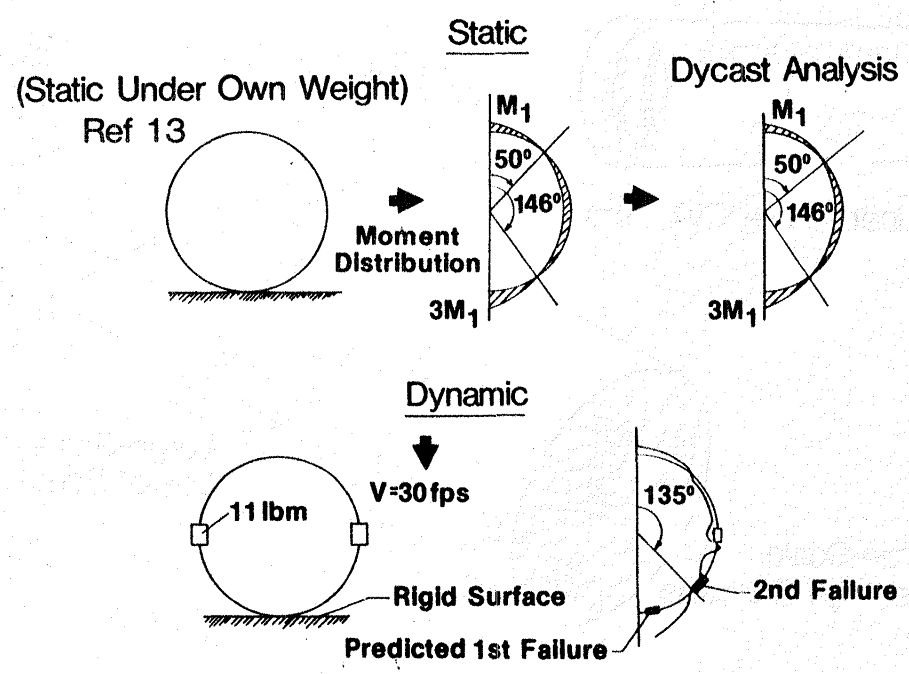


Figure 14

SUBSTRUCTURE LEVEL STUDIES

The third level (large-scale substructures) in the NASA composite impact dynamics program is the most ambitious of the efforts to help achieve the overall goal of providing the necessary data base needed to support the introduction of advanced composite materials into fuselage structure of future transport airplanes. Although the full-scale substructures that are illustrated in figure 15 are expensive, these substructures would provide the confidence level required before proceeding to production by exercising the design and analysis methods and the manufacturing and inspection procedures that are critical requirements. Data from the full-scale substructure level should allow evaluation of the effects of design restraints, multi-element interactions, and combined loading on crash behavior. Furthermore, substructure load deflection data along with the element level data are highly desirable to permit validation of analysis methods, which can in turn be used to predict the sensitivity of response to a wide range of variations in design or load. It is also important that the crash behavior of the substructure be known since this is critical to the understanding of the response of the floor structure and subsequently of the occupants.

Efforts at this level of the generic composites program in all likelihood will rely on contractural efforts such as continuations of the ACEE program or follow-on programs. Indeed, one such contractural effort is discussed in a subsequent section.

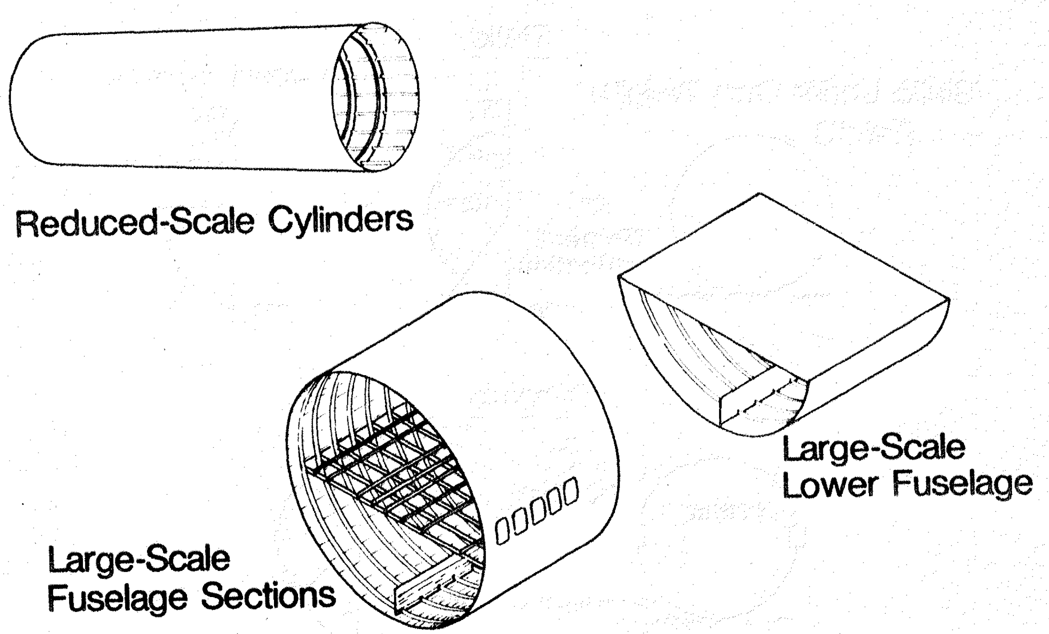


Figure 15

METAL TRANSPORT SUBSTRUCTURE DATA BASE STUDIES

As part of the NASA Langley Research Center's transport crash test program (ref. 14), various fuselage sections from transport aircraft (Boeing 707) have been acquired for dynamic drop testing. The purpose of these tests (see refs. 15 and 16) is to determine structural, seat, and occupant response to vertical loads. This effort is part of the support of the full-scale controlled-impact demonstration (CID) test of a remotely piloted Boeing 720 airplane to be conducted at NASA/Dryden as part of a joint NASA/FAA program. Additionally, the structural response data will permit correlation of the capabilities of the DYCAST computer program (ref. 12) being developed for crash analysis of aircraft structures, and will provide a metal transport substructure data base for comparison with tests of any future composite fuselage structure. Figure 16 presents typical experimental and analytical results for a transport section located forward of the wings of the airplane. During the impact, the lower fuselage section collapsed upward approximately 24 inches as a result of tensile failures which occurred along holes beneath the baggage compartment floor due to bending and shearing out of bolt holes along the edge of the floor covering. DYCAST predictions (Hayduk, R. J.: NASA LaRC) using a two-frame model for this section are in excellent agreement with the experiment. For example, the predicted deflection of the underside of the fuselage of 22 to 23 inches compares well with the measured deflection of about 24 inches. The physical behavior also matches the observed behavior of the test section. Additionally, the magnitude and basic lower frequency content of the accelerations at the intersection of the passenger floor and the outer cylindrical fuselage structure are in good agreement. Structural stiffnesses have been developed from the simpler analytical models of the fuselage for formulating an analytical model of the complete Boeing 720 airplane. This larger model is being used to study dynamic behavior and failure of the aircraft under various impact scenarios. The data from both the sections and the full-scale airplanes will serve as part of the data base relative to composite impact dynamic studies which are discussed in the next section.

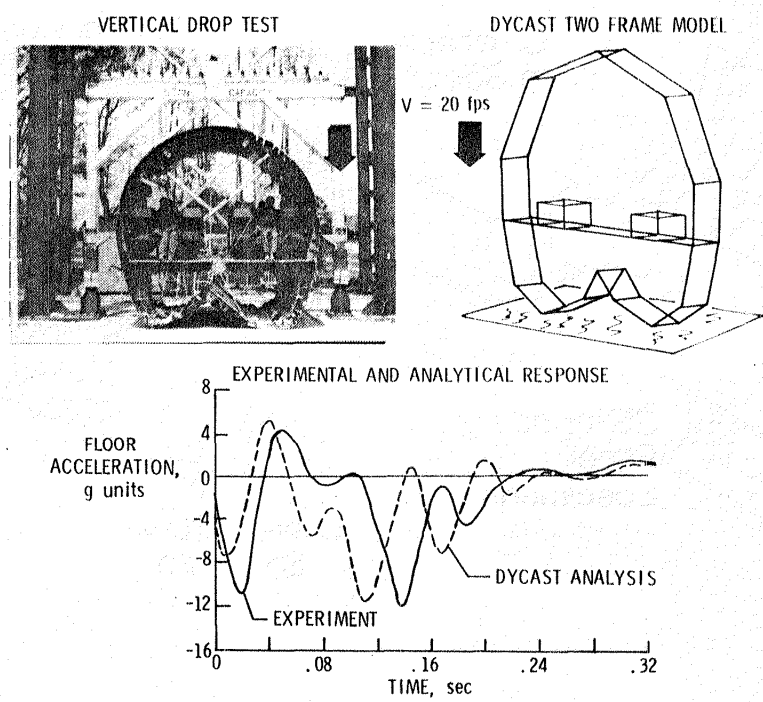


Figure 16

COMPOSITE FUSELAGE SUBSTRUCTURE STUDIES

One highly desirable phase of research on composite impact dynamics is the composite fuselage substructures studies. This part of future efforts on impact dynamics should parallel the past and on-going studies on metal fuselage components. It is apparent that difficult manufacturing requirements and high costs would at present accompany the fabrication of large-scale composite fuselage components such as illustrated in figure 17. Consequently, it is probable that projects such as the continuation of the Aircraft Energy Efficiency Program or similar follow-on programs in composites would be by necessity the vehicle for obtaining and/or conducting such substructure studies. As a matter of fact, proposed contractural efforts addressing major technology issues including impact dynamics are being considered by the ACEE Project Office. As illustrated in figure 17, various subelement studies would support the initial study of large-scale subcomponents of the fuselage. Indeed, as shown in the figure, the initial structure of the proposed effort is not a full section or floor and lower fuselage shell but addresses only the lower crown region of the fuselage. Full-scale sections, because of their cost, would necessarily incorporate not only impact dynamics (crashworthiness) considerations but also include other technology issue areas such as fatigue, damage tolerance, and acoustic transmission design concepts.

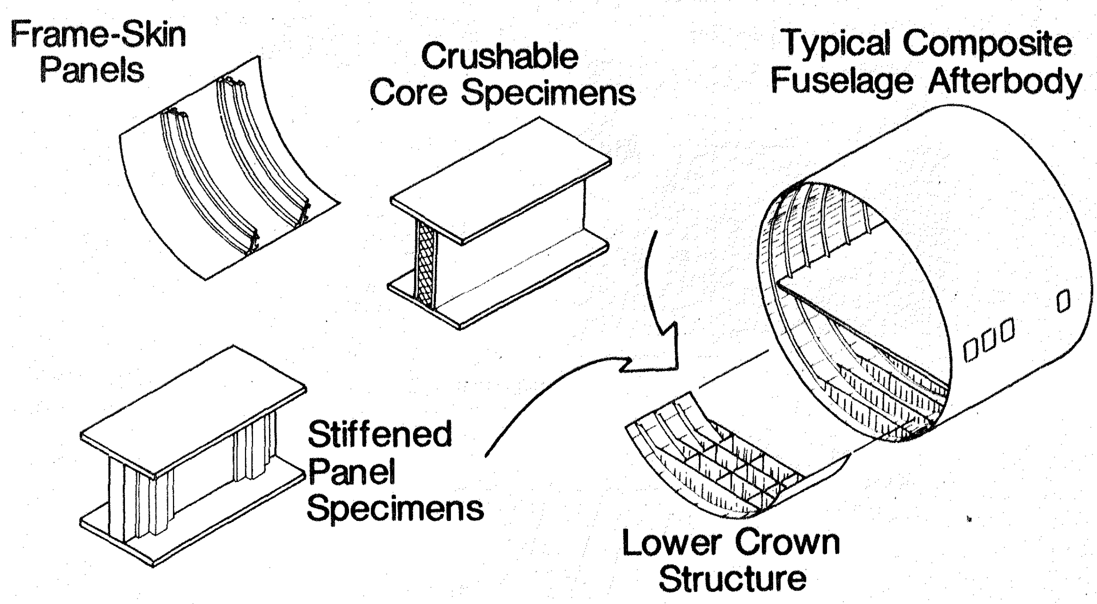


Figure 17

CONCLUDING REMARKS

The Langley Research Center's Crash Dynamics Group is in transition from a general aviation crash test program to transport-related research. A composites impact dynamics program (still in its infancy) has been formulated to focus on composite laminates, composite structural elements, and composite substructures. Studies are being conducted to investigate the impact dynamics behavior (crashworthiness) of generic composite components subjected to crash-related loadings. Supporting analytical efforts are also a part of the research efforts.

Results of studies on energy absorption on the composite laminate level indicate that composite materials (Gr/Ep) can absorb more energy than aluminum but may have poor post-crush structural integrity. Making use of knowledge of the different failure mechanisms of various composite materials is leading to hybrids of high-strain-to-failure graphite woven with Kevlar, which appears to provide higher energy absorption but has post-crush integrity.

Tests of composite skin materials subjected to inplane and out-of-plane (mode I and III, respectively) tearing loads indicate that Gr/Ep panels generally compare to 7075-T76 aluminum in energy-absorbed and resisting tears whereas hybrids (using glass) generally compare to the more ductile 2024-T3 aluminum.

Abrasive loads on composite fuselage skin materials may have a major influence on the potential repairability of composite fuselage underbelly panels that experience abrasive loads during gears up or collapsed-gear emergency landings. Laboratory tests indicate that the composite materials, both standard Gr/Ep and Gr/toughened epoxy, exhibit wear rates 5 to 8 times higher than aluminum under identical test conditions. Friction coefficients for Gr/Ep were 50% that of aluminum (0.2), whereas aramid and toughened composites were about the same as aluminum. Runway tests will be correlated to the laboratory tests to verify and extend this data base.

Curved panel elements on the underside of composite fuselage structure would also be subjected to radial impact loads; therefore, experimental and analytical studies on circular composite panels were undertaken. Results from the studies have indicated panel shallowness, material orthotrophy, and stacking sequence influenced the nonlinear response of the panels.

Crushing behavior of composite and aluminum keelson-like beams indicated that all materials (Gr/Ep and hybrids) were very similar in energy absorbed; however, the failure mode for the aluminum (fracture) was different from the delamination/buckling failure of the composites. Improved hybrid composites developed under the Army/NASA energy absorption study should be evaluated for potentially achieving higher specific energy absorption.

Both experimental and analytical studies have been initiated to not only determine the large deformation response and failure of composite beams subjected to impact buckling loadings but also to investigate the dynamic response and failure loads/modes of curved composite frames (Z-cross section).

On the substructures level, metal transport sections have been dynamically tested and are being analyzed using the DYCAST nonlinear finite-element computer codes. Good correlation was indicated between large deflection/failure of the fuselage understructure and floor accelerations and DYCAST predictions. These tests along with a full-scale controlled-impact demonstration (CID) test of a Boeing 720 airplane will serve as the metal data base for possible future composite substructure tests and provide validation of the DYCAST computer program for crash analysis of aircraft structures.

Future composite substructure studies are highly desirable and should parallel past and on-going metal structure research. A proposed initial composite fuselage study will focus only on the lower crown with subelement support tests. Because of

the cost, the full-scale composite fuselage structure will by necessity involve other technology issues such as damage tolerance and acoustic transmission along with the impact dynamics (crashworthiness) behavior.

REFERENCES

1. Davis, G. W.; and Sakata, I. F.: Design Considerations for Composite Fuselage Structure of Commercial Transport Aircraft. Lockheed-California Company, Burbank, California, NAS1-15949, NASA CR-159296, March 1981.

2. Alfaro-Bou, Emilio; Williams, M. Susan; and Fasanella, Edwin L.: Determination of Crash Test Pulses and Their Application To Aircraft Seat Analysis. SAE Tech. Paper 810611, April, 1981.

3. Carden, Huey D.; and Hayduk, Robert J.: Aircraft Subfloor Response to Crash Loadings. Paper 810614 presented at SAE Business Aircraft Meeting and Exposition, Wichita, KS, April, 1981.

4. Thomson, Robert G.; Carden, Huey D.; and Hayduk, Robert J.: Survey of NASA Research on Crash Dynamics. NASA TP-2298, April 1984.

5. Carden, Huey D.: Correlation and Assessment of Structural Airplane Crash Data With Flight Parameters at Impact. NASA TP-2083, Nov. 1982.

6. Carden, Huey D.: Impulse Analysis of Airplane Crash Data With Consideration Given to Human Tolerance. Paper 830748 presented at SAE Business Aircraft Meeting and Exposition, Wichita, KS, April 1983.

7. Farley, Gary L.: Energy Absorption of Composite Materials. NASA TM-84638, AVRADCOM Technical Report TR-83-B-2, March 1983.

8. Passengers Praise Pilot for Actions in Accident. Times-Herald (Newport News, VA), 83rd year, no. 71, March 24, 1983, p. 13.

9. Jackson, Karen, E.: Friction and Wear Behavior of Aluminum and Composite Airplane Skins. NASA TP-2262, AVRADCOM TR-83-B-7, February 1984.

10. Carper, Douglas M.; Hyer, Michael W.; and Johnson, Eric R.: Large Deformation Behavior of Long Shallow Cylindrical Composite Panels. M.A. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, VPI-E-83-37, September, 1983.

11. Johnson, Eric R.; Hyer, Michael W.; and Carper, Douglas M.: Response of Long Shallow Cylindrical Panels To Radial Line Loads. Presented at AIAA/ASME/ASCE/AHS, 25th Structures, Structural Dynamics and Materials Conference, Palm Springs, California, AIAA-84-0954-CP, May 14-16, 1984.

12. Pifko, A. B.; and Winter, R.: Theory and Application of Finite Element Analysis to Structural Crash Simulation. Computers and Structures, Vol. 13, pp 227-285, 1981.

13. Van Den Broek, J. A.: Elastic Energy Theory. John Wiley and Sons, Inc., New York, Second Edition, August 1946. pp. 108-117.

14. Thomson, R. G.; and Caiafa, C.: Designing for Aircraft Structural Crashworthiness. Journal of Aircraft, Vol 19 No. 10, AIAA 81-0803R, Oct. 1982.

15. Williams, M. Susan; and Hayduk, Robert J.: Vertical Drop Test of a Transport Fuselage Section Located Forward of the Wing. NASA TM-85679, August 1983.

16. Williams, M. Susan; and Hayduk, Robert J.: Vertical Drop Test of a Transport Fuselage Center Section Including the Wheel Wells. NASA TM-85706, October 1983.

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16. Abstract

A Langley Research Center crash dynamics program has been formulated to investigate the response of generic composite components to simulated crash loadings. This paper discusses initial results of experimental and analytical inhouse, university grants, and contractural investigations of generic advanced composite components appropriate to transport fuselage construction subjected to crash-related loadings.

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